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A NEW POINT LOCATING SYSTEM FOR HIGH-CURRENT UNDERGROUND CABLE

- Germany -

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[Following is a translation of an article by Hans Henneberg in the German-language company periodical Siemens Zeitschrift, (Siemens Periodical), No. 11, Nov. 1959, pages 698-703.]

The high load of consumption on cable nets demands a quick removal of cable disturbances. Duration and cost of repair are dependent upon the exactness of the locating-measurement. Further reduction of the measuring error is not possible when using the conventional measuring technique, which determines the distance of the faulty spot from the starting point of the cable. The demand for a faster and considerably more precise location of the trouble spots can therefore be fulfilled only by spot-checking the cable. Because of the great consequence in regard to current supply which an exact spot location has, the solution of this problem has been included in the development program of the Werner Works for Measuring Techniques. The result of these development experiments is a new point locating system with all the equipment needed for it.

In a planned fault location under this system three successive steps must be taken:

Preparation of the Faulty Spot

For this, Burning Apparatus I[1] is designed. The apparatus-with built-in automatic - is fitted to the various problems of the Point Locating System, which can then be executed safely and with sure aim, namely:

Making extremely low-ohm connections of about 0.1 Ω between two conductors,

Changing of a one-conductor ground contact into a multiple-conductor contact,

Burning down of a high-ohm transit resistor or of a spark-over to 1 Ω and lower,

Feeding of a cable with a spark-over for the acoustical location.

Limiting of a Faulty Spot

To limit the point location on the cable to within the smallest possible length, the faulty spot shall be roughly determined by pre-measurement. An apparatus especially suited for this is the REFLEKTOGRAPH* I[2], which already has come into wide use. On this apparatus the reflexions of the cable are shown on two electron beam tubes for fast and clear orientation. The tube Lupe [Magnifying Glass]

shows a greatly magnified section and the Over-all View Tube shows the total reflexion view, of which the desired section can be focused upon. The sectional view can be "moved along" with the help of a slide mechanism so that one can "look along" the reflexion picture, which stretches over 700 mm. The distance to any reflexion point can be read directly in meters.

Direct Point Location on the Cable

For this purpose the GEOSKOP has been developed, about which shall be reported in the following.

FIELDS ON THE CABLE

When a cable is fed with sound-frequency current or with HF-impulses, under certain conditions fields will appear at the cable which will change at the faulty point. These fields can be received and shown with search coils. Sound fields, created by spark-overs at the faulty point, can also be located. These fields are the basis for point location on the cable and shall therefore be examined next.

Mantle Field

A mantle field (Ill. 1) appears when pole A of a audio-frequency (TF) generator is connected with a conductor and pole B with the mantle of the cable. During a half-wave the current flows from pole A via the conductor to faulty spot C, there to the mantle and back to pole B. Part of the mantle current escapes via the soil. In the assumed current branch net of Ill. 1, the difference between conductor and mantle current is zero at the cable start; it increases then and decreases again toward the faulty spot and beyond. The faulty spot will not show up. Therefore, a mantle field is ill-suited for fault location; but it is favored, because of its great intensity, for tracing a cable with simple means. One does not always obtain clear results this way. The current escaping via the soil can accumulate in other conductors, which will then show a similar field as the cable to be traced and possibly can cause a mix-up.

Twist Field

As shown in Ill. 2, a twist field occurs when the TF-generator is connected with two conductors of the cable and the conductors are connected at the faulty point or at the end. Since the twisted conductors are spatially separated, every half "twist" equals one long-drawn "spiral" through which current flows and in which a magnetic field occurs. The magnetic field in "coil" 1 is opposed to the magnetic field in "coil" 2, etc. Past faulty spot C the magnetic fields, which change with the twist, will end, since no current flows there. The twist field also makes it possible to follow the cable exactly and to recognize the couplings since the conductors run parallel in a coupling and the rhythmic twist is therefore interrupted.

HF-Impulse Field

It has been often attempted to develop methods by which one-conductor cable fields can be located with direct current or sound frequency currents. In case of a one-conductor fault the currents flow across conductor and mantle in a loop. Thus develops the already described mantle field, which is unsuitable for the point location since the current distribution depends on the transitional resistances of the soil.

The spread of HF-impulses, on the other hand, follows different laws; they spread like sound waves. When a cable is fed several interconnected short impulses between conductor and mantle, the impulses will spread on the cable with a speed which is determined by the cable type.

The field of the mantle is neutralized by the field of the conductor so that no effective field develops outside of the cable. When the HF-impulses reach the faulty point, at which a small hole has been burned into the lead mantle, impulse energy will escape at this point and will radiate off to all sides. In order to detect reliably with electronic means the fields which in this manner occur above the soil, the sender must produce impulse output up to 200 kW.

Ill. 3 shows the course of an HF-impulse field at the soil surface above a faulty point. The cable lay 90 cm deep and had a 1 cm^2 hole in the lead mantle at the faulty point. The steel armor was not damaged. With this field distribution the faulty spot can be determined to within a few centimeters.

Sound Field

In addition to the three magnetic fields named, namely the mantle field, the twist field, and the HF-impulse field, the sound field also plays an important role. It develops through spark-overs on the cable or in a coupling and makes the exact locating of the spark-over in a simple manner possible. With proper means, spark-overs can also be generated in the case of relative low-ohm transitional resistance at the faulty point, so that accoustical spotting can be employed in cases of almost all types of faults.

Ill. 4 shows the intensity distribution of a sound field which was caused by spark-overs on a cable buried at 80 cm depth. As energy reservoir served here the capacity of the conductors against the mantle of the approximately 1.2 km-long 30-kV cable.

PROBLEMS AND EMPLOYMENT OF THE POINT-LOCATING SYSTEM

These various fields, which clearly mark the faulty spot, make basically possible direct locating on the cable and thereby fulfill practical needs. Yet, planned direct locating has not, up till now, achieved any significant importance. Further systematic development therefore had to proceed from the facts responsible for this lack of importance:

1. A faulty spot can be located with a twist field only when the latter is shown clearly and crisply and when it ends behind the faulty spot as if cut off. But this requires that the transitional resistance between the conductors at the faulty spot must lie below 1 Ω and, in addition, that the frequency of the transmitter must not surpass appreciably 500 Hz. If the burning apparatus used is not suitable for the production of such low-ohm and stable-current transitional resistances between the conductors, the mantle at the faulty spot will be fed by the conductor. Therefore, equalizing currents will flow in the mantle; they produce a mantle field which superimposes on the twist field and thereby makes the twist field unrecognizable. The mantle field runs past the faulty spot and the faulty spot cannot be found any more.

But the disturbing mantle field can also be caused by too high sound frequency or by a transmitter current which is not sine-shaped. In this case, disturbing capacitive equalizing currents will flow in the mantle because of the unsymmetricalness of the cable.

2. A further reason, why direct locating on the cable has not been considered as being very significant heretofore, has been the absence of a system by which a one-conductor ground contact can be located. Also, changing the one-conductor fault into a multiple-conductor fault, over which then can be produced the twist field, is difficult with simple means.

3. In addition, the interference field, which almost always occurs on cables, has a basically unfavorable effect. One can distinguish between the periodical and the aperiodical interference field. A periodical interference field develops mainly through nearby live cables and is produced by the net frequency and the upper harmonic waves. On the other hand, an aperiodical interference field is caused, for example, by switching processes, which occur occasionally.

An aperiodical interference field cannot be filtered out with ordinary means since it contains a wide frequency spectrum and therefore would jog every sound-frequent oscillatory circuit. This prohibits then, when an aperiodical interference field exists, the use of oscillatory circuits for the repression of the periodic, sound-frequent interference field. For this reason it has been customary up until now, to work almost without filter elements and to leave the differentiation between the search field and the superimposed interference field to the human ear. Since the intensity of the interference field often ranges far above that of the search field, the application of the direct-locating method is sharply limited when utility and interference field are shown simultaneously.

OPERATION OF THE GEOSKOP

Transmitting Side

The audio-frequency generator is shown in Ill. 5 and 6. The frequency of the oscillator can be tuned in on six channels of 450 to 500 Hz. It [the frequency] is largely kept constant out of regard for

the filter element of the receiver. The voltage of the oscillator governs the amplifier and can be interrupted periodically with a keying circuit. Furthermore is it possible to superimpose a marker, which switches the transmitter current off at intervals of 2 min.

The amplifier produces a starting output of 100 or 200 W. The adjusting part facilitates a good adjustment to the complex resistor of the cable.

The high-frequency impulse generator is connected to the outlet of the TF-generator and is fed by the latter's TF-energy. It [the HF-impulse generator] stands during the locating operation next to the cable starting point. Ill. 7 shows its operation.

The ratio transformer changes the current-voltage ratio of the output delivered by the TF-generator and feeds it to the energy reservoir. The accumulated energy is rhythmically withdrawn by the impulse switch and is fed to the cable via the impulse transformer. The impulses have a peak capacity up to 200 kW. The HF-impulse generator is contained in a pipe-shaped housing which is air-cooled by a blower. At the front of the impulse generator is a socket for the reception of the attachable impulse transformers. There are three versions [types] available in order to be able to produce various sequences of impulse frequencies.

The sound field is caused by spark-over at the faulty point on the cable or in the coupling. It occurs in the same way on a one-conductor ground contact as on a multiple-conductor contact. With the new acoustical locating system of the GEOSKOP can therefore almost every kind of cable fault be located to the spot. The acoustical locating system cannot only be used when a high transitional resistance exists at the spark-over; cable faults with low-ohm transitional resistance can also be located acoustically. In this case, special methods are used to generate spark-overs.

The spark-overs should have a maximum intensity. For cables buried at less than 80 cm depth a capacity of approximately 0.5 μF at a load voltage up to 20 kV suffices as energy reservoir. Lies the cable deeper, or lies the faulty point close to a busy street with a high noise level, capacitors up to 2 μF are required. As capacitors can be used the fault-free conductors of the cable to be checked, a second cable, or a shockproof supplementary condensator. Is the transitional resistance at the faulty spot very high or infinite, as for example, at air-caused spark-over in a coupling, the faulty conductor, and, if required, also the capacitor are charged against the mantle with Burning Apparatus I.

As mentioned already, low-ohm faults can also be located acoustially. In such case, one must either burn the existing carbon connection at the faulty spot with appropriate manipulation of the burning apparatus, or feed to the faulty conductor of the cable with its low-ohm fault resistance steep, very energy-rich high-tension impulses. Thus the acoustical fault location offers a variety of possibilities for application.

Receiver Side

Search Coils

The electrical fields on the cable are received by TF or HF-search coils and then changed into tension [voltage]. The TF-search coil consists of a very low-capacity coil with an iron core of high permeability. The natural frequency of the coil lies outside of the frequency area to be received so that it cannot similate a search field when it is electrically jogged by aperiodical interferences.

Mantle fields, with which the course of a cable can be traced, are basically received only with a search coil. Twist fields, too, can be traced with a single search coil. However, it has considerable advantages to use two reciprocally connected coils which lie serially in direction with the cable and which have the twist distance. In this way the usable tension is doubled and the interference tensions are almost neutralized.

This coil arrangement, which extends considerably the area of application of direct locating, is a distinct characteristic of the GEOSKOP. Ill. 8 shows the searching rod with the searching coils with the organic holding rig. If only one searching coil is to be used, the pictured holding rig is exchanged for one which is appropriate.

The TF-search coils are made to reach under normal conditions a depth up to two meters. If locating is required in greater depth and on very long cables it is recommended to plan on the use of a 200 W generator. But special coils, which have a greater profile and therefore are correspondingly heavier, can also be used. In practice, depths up to 10 m have thus been measured.

For the reception of impulse fields an HF-search coil has been developed which can be tuned to various frequency channels; it has the same dimensions as the TF-search coil and can be affixed to the searching rod by the same holding rig.

Sound Receiver

The sound field can be received with one or with two special sound receivers. Tuning in of two sound receivers alternately facilitates the locating of the faulty spot since the sound receiver closest to the faulty spot will register the greatest deflection. The sound receivers can in this way be relocated continually until, by maximum sound volume, the faulty spot has been exactly located.

Receiver

The receiver is carried on a shoulder strap (Ill. 9). It contains 9 tubes and the means for repressing and filtering-out of the interference level. The coil A (Ill. 10) supplies a tension which pilots the first tube via the electric filter B. The filters B filter out the periodical and the filters C the aperiodical interference tensions. In the outlet of the sixth tube lies the filter D with a mechanical oscillator. This enables it, in coordination with the electrical filter circuit, to sense the search field undisturbedly,

even in a strong interference field. The frequency range of this filter, whose resonance frequency and filter discrimination are adjustable, is shown in Ill. 11. The solid line represents the greatest and the broken line the smallest adjustable discrimination. The unusually high discrimination is a prerequisite for the effective application of the point locating system. Under the given conditions it can be achieved only with an adjustable mechanical oscillator. The transformer E has the function of changing the sound-frequent alternating current in the outlet of tube 9, the height of which is an indication of the received field strength of the search field, into acoustical impulses. Neither an impulse nor any other noise is audible in the earphones if no search field is present, even when the search coil is held into the interference field of an approaching streetcar. When the field to be located is approached, loud noise impulses will appear, whose time interval is an indication for the strength of the field. The impulse frequency of the noise impulses lies between 0 and 20 Hz. The scale is logarithmically dense. This kind of representation, which also is effective in traffic noise, has proven itself to be very advantageous in practice. Simultaneously the intensity is shown on the measuring instrument, which is fastened to the side of the receiver.

When depressing the appropriate operating key, the receiver of the GEOSKOP will also work without the mechanical filter. This makes it possible to make the search field concurrently audible with the other fields. In this way can, for example, active current supply cables be searched and traced.

During acoustial locating the mechanical filter is also turned off. The electrical filters, which thereby become active, so strongly repress the interference noise that a further area of application has been opened for the acoustical locating method. With the operating key control the sensitivity of the receiver can be changed from a 1: 1 to a 1: 1,000 ratio.

With the turning know in the searching rod the sensitivity is continually adjusted.

HF-impulse Adapter

HF-impulses are generated with a frequency ["frequency" here means "abundance", "regularity"] which corresponds to the frequency [electrical here] of the TF-generator that feeds the impulse producer. The HF-impulse adapter boosts the very low tensions at the HF-search coil and changes them into a sound-frequent tension. This tension is fed to the input of the TF-receiver.

Noise impulses or deflections are presented in the same manner as when receiving the TF-field.

The filters of the adapter can be tuned with a channel selector to match the time interval of the HF-impulses sent out.

OPERATIONAL EXPERIENCES WITH THE NEW POINT LOCATING SYSTEM

Which method should be used for the locating of a faulty spot depends primarily on the kind of fault. An HF-impulse field and a sound field develop only on the faulty point proper. A twist field, on the other hand, leads up to the faulty point. Since locating by way of the twist field is the simplest and requires no additional apparatus, this method should always be preferred. In connection with Burning Apparatus I it is suitable for by far the most common types of cable faults.

Of many practical experiments a few shall be given here as characteristic examples:

1. Example One

The conductors of a 1 kV cable are burned off. Length of cable approximately 3 km. The course is unknown.

a. Measuring-in of the faulty spot with REFLEKTOGRAPH I at 2,600 m. Point locating also started from the other end.
b. Burning conductor - mantle and then conductor - conductor.
c. Start operating TF-sender.
d. Follow twist field from the beginning of the cable. Faulty spot lies exactly there, where noise impulses cease.

2. Example Two

Three-mantle cable 30 kV with one-conductor ground contact. The transitional resistance is high-ohm.

a. Burning with initial potential. If no breakdown occurs, then (see b).
b. Measuring-in of the now low-ohm faulty spot with REFLEKTOGRAPH I.
c. Start operating HF-impulse sender.
d. Employ HF-impulse receiver at pre-measured fault location.
e. Follow course of cable (if course insufficiently known, determine course on twist field prior to HF-impulse location).
f. Noise impulses appear suddenly which disappear again after a few meters. In the middle of this distance is a point at which, depending on the position of the searching coil, the noise impulses cease or have reached their maximum. There exactly lies the faulty spot.

3. Example Three

Spark-overs occur in a 6 kV cable of 2 km length at 8 kV test tension. The faulty conductor has normal insulation resistance. Cable plan not available.

a. Burning of faulty conductor without success. Faulty point is probably in a coupling.
b. Connect two conductors at the end and connect TF-sender.

c. Follow cable course with TF-receiver and determine couplings.
d. Connect Burning Appratus I with faulty conductor and adjust charging current to produce approximately one spark-over per second.
e. Follow cable course and set sound receiver on the marked couplings. The coupling in which the spark-overs occur can be recognized immediately.

These examples show how the new point locating system can be worked to achieve results.

Notes:

(1) Henneberg, H.: A New Cable-Burner and Test Applicance. Siemens-Periodical 31 (1957) 269-274.
(2) Henneberg, H.: The Reflektograph. Siemens-Periodical 26 (1952) 312 to 316.

* Registered Trademark.

FIGURE APPENDIX

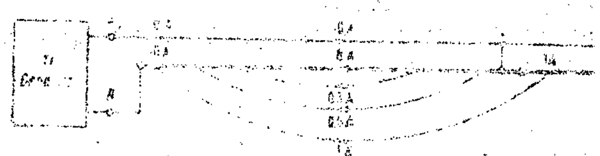


Figure 1. Mantle field of a high-current cable with faulty spot at C.

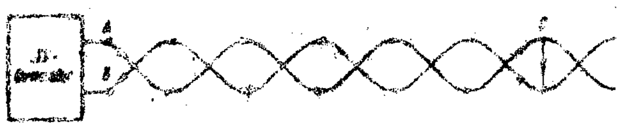
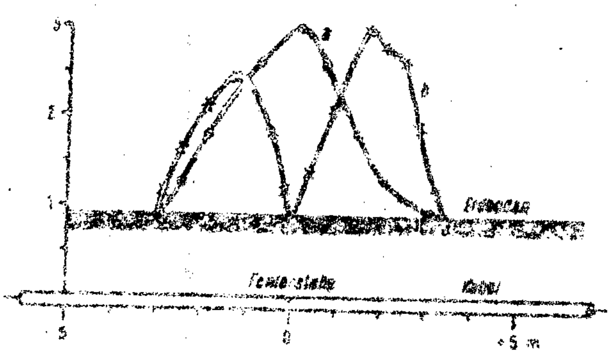


Figure 2. Twist field produced by conductor current on a cable faulty at C.



Soil Surface

Faulty Point Cable

Figure 3. Course of field of the HF-impulse field at the faulty point.
Curve a: Coil lined up with cable; Curve b: Coil vertical to the cable.

Declination on Instrument

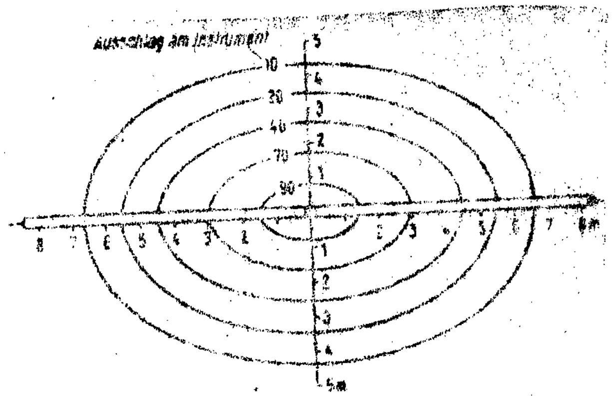


Figure 4. Intensity distribution of a sound field on the soil surface.

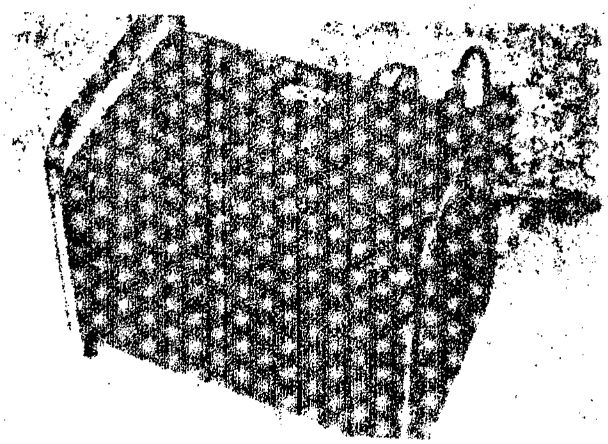
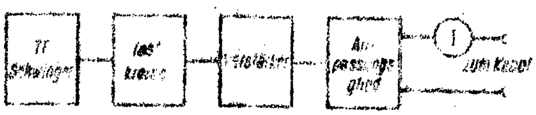
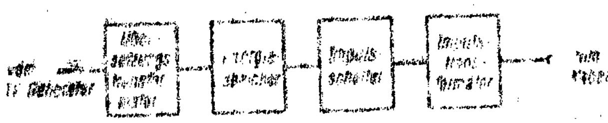


Figure 5. GEOSKOP, audio-frequency generator.



TF
Oscillator   Amplifior   to the Cable

Figure 6. Block circuit of the audio-frequency generator.



From TF-generator   Ratio Transformer   Energy Reservoir   Impulse Switch   Impulse Trans-former   to Cable

Figure 7. Block circuit of HF-impulse producer.

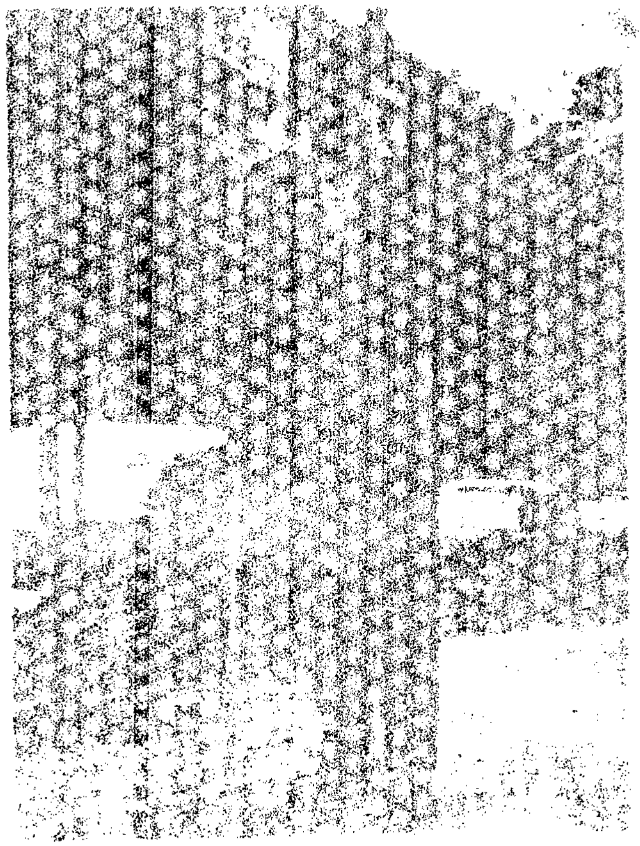


Figure 8. GEOSKOP, audio-frequency receiver with searching rod and differential coils.

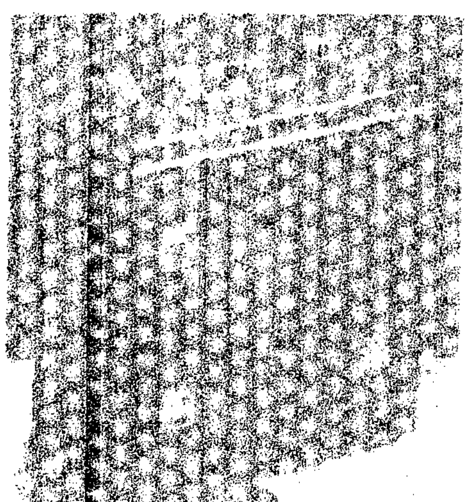
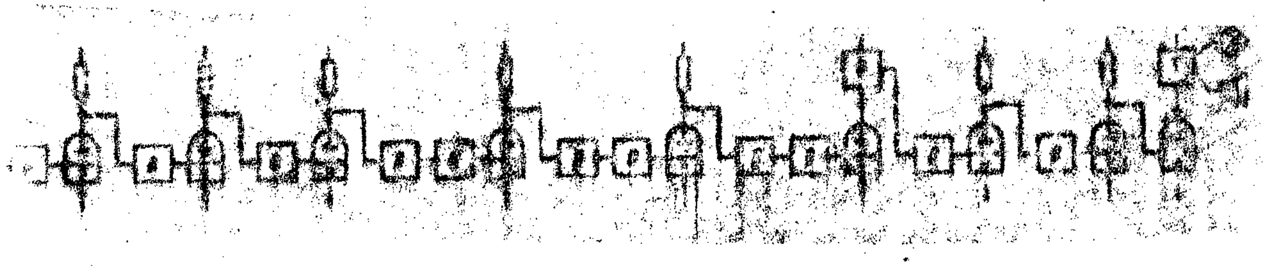


Figure 9. GEOSKOP, audio-frequency receiver.



A Search Coil
B Filter for Periodical Interference Field
C Filter for Aperiodical Interference Field
D Mechanical Filter
E Transformer

Figure 10. Block circuit of the portable-audio-frequency receiver.

Terminal Tension

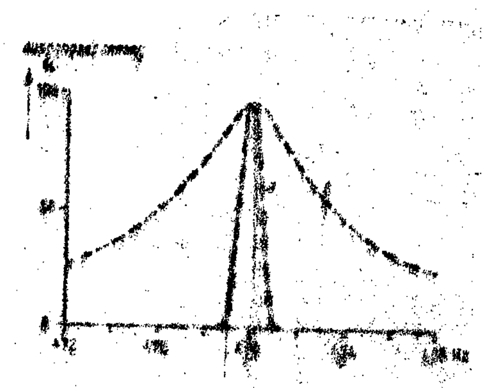


Figure 11. Adjustable frequency flow of the mechanical filter.
Curve a unsuppressed; Curve b: suppressed.

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